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Early Opportunity for CO_2 Capture from Gasification Plants in China

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Abstract

A qualitative assessment of the early opportunities for capturing carbon dioxide from advanced gasification plants, and of design guidelines for carbon capture ready gasification plants in China, is conducted to investigate current development in coal gasification. The assessment first illustrates the development of different types of gasification technology in China. Capturing carbon dioxide from high concentration stationary emission points could be seen as an early opportunity for carbon capture demonstration. The large scale CTL plants and chemical plants installed with advanced entrained flow gasifier should be considered as early opportunity for CCS in China. However, given that the total amount of emissions and the scale of emission sources are relatively small at those plants compared with conventional coal fired plant, the potential emission reduction is very limited.

Keywords: CO_2 Capture, Gasification, Capture Ready, China, CTL

1. Introduction

Although most of the less advanced gasifiers are used to produce ammonia, urea and hydrogen on a small scale[1], during the past decade, large size entrained-flow gasifiers were introduced to the industry. Large-scale coal to liquid (CTL) or coal to chemical (CTC) plants could consume around 2000 tonnes of coal per day per gasifier. Greenhouse gas emissions from these plants are much higher than that from plants with smaller scale gasifiers. A number of those plants using advance entrained-flow gasifiers are in the process of applying for expansion as well [2]. Hence, applying carbon capture technology, especially making those plants CO_2 capture ready (CCR) or integrating new plants into a CCS ready hub, could

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provide significant economic and technical benefits on emission reductions in the [3,4,5]. Integrated Gasification Combined Cycle (IGCC) is regarded a strategically important technology in China [6], but there is no plant in operation in China at the moment, except the Greengen IGCC power plant in Tianjing [7].

The additional cost of carbon capture in gasification process systems was projected to be significantly lower than the cost of capture from pulverised coal (PC) plants [8]. Gasification was also considered as one of the most important coal transformation technologies for China [9]. Since China has the largest number of gasifiers around the world, it could be practical and economical to start capturing carbon dioxide from some of the gasification plants in the near future, such as ammonia, urea and hydrogen plant. This does not necessarily mean capturing CO_2 immediately, but planning the plants so that they could be easily and economically retrofitted into a carbon capture plants later on, or even be used as an early opportunity for a carbon capture and storage (CCS) demonstration project.

Capture ready design could be as simple as leaving sufficient space for additional shift, capture and compression units and having undertaken a feasibility study to ensure a retrofit can be undertaken readily. An economic simulation conducted by [10] indicates a very significant option value of CO_2 capture ready in the large conventional Chinese coal-fired power plants. However, it is widely recommended that new IGCC plants should be built with carbon capture rather than being only carbon capture ready [11], because from a technical point of view it is hard to match the gasifier output and the turbine capacity both before or after capture retrofit. Economically, capture ready cannot demonstrate a great saving in the overall IGCC capital investment. Hence, this paper will only discuss the capture retrofit potential for existing plants installed with advance entrained –flow gasifiers.

2. Protential CCS applications using entrained-flow gasifiers

2.1. Advanced fluidised bed and entrained –flow gasifier technology

Entrained-flow gasification technology can be used in producing syngas, fuel and generating electricity. The technology has been recommended as a replacement for the intermittent fixed-bed gasifiers in small to medium scale nitrogenous fertilizer plants. In order to save costs, it can also use soft coal instead of anthracite in synthesis ammonia production. This means that the plant owner will have a wider choice of coal for feeding into the gasifier, and therefore can select the coal locally and reduce the transportation costs for better ranking coal elsewhere. In an entrained-flow gasifier, fine coal particles (<100μm), either dry or in a slurry form, are reacted with steam and oxygen at high temperatures (~ 1600ºC) and elevated high pressures (40 bar to 70 bar). Coal conversion rates are high, for example, the current operating Shell gasifier has a throughput of 1000 - 2250 tonnes/day; a GE gasifier has a throughput of 350 - 2200 tonnes/day; and the throughput of a Siemens gasifier is normally 2000 tonnes/day [12]

GE, Shell and Siemens are the main technology providers for installed Chinese entrained-flow gasifiers. Chinese entrained-flow gasifier technology is being developed by the Thermal Power Research Institute (TPRI) in Xian, Shan'xi, and East China University of Science and Technology (ECUST) has also invented the two-stage gasifier and the Multi-Burner Opposed Nozzle (MBON) gasifier [13].

Both Shell and GE started their gasifier businesses during the 1980s by providing residue oil gasifiers for visbreakers[d] in China. 12 of these plants are still running [14]. But with oil prices running high in recent years, building refinery gasifiers which use residue oil are not an economic investment any

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[d] *A processing unit in oil refinery which aims to produce more expensive products and reduce the amount of heavy residue produced.*

more. While the oil price has increased more than coal price in recent years the final products for both feedstocks are sold at a similar price in most areas. Therefore this paper will not cover this technology. There are currently 19 coal slurry gasification plants using GE gasifiers, 18 Shell dry coal gasification plants in operation and 9 in construction, and another 2 Siemens large scale CTL plants [12,14,15] . GE started to sell coal gasifiers in 1993, while Shell started to build gasifiers in 2006. On average, Shell and Siemens have been providing gasifiers with a coal consumption rate of 2000t/d in recent years [14].

2.2. Entrained-flow gasifier in chemical applications already producing concentrated CO_2 streams

Most of the large-scale entrained flow gasifier plants produce methanol, dimethyl ether (DME) as transportation fuel or feedstock for the production of other chemicals with entrained-flow gasifiers. Because oxygen is used as feedstock instead of air, highly concentrated hydrogen is produced during the process. Therefore, carbon dioxide could be captured at the cost of adding a compression and storage unit on site. The treatment afterwards is similar to that used in fixed-bed gasifiers, using oxygen as feedstock.

2.3. Entrain-flow gasifier in large-scale coal-to-liquid plants

The Shenhua[e] direct liquidation plant in Erdos produces 4.16 million tonnes of carbon dioxide each year, of which 70% has a carbon dioxide concentration of over 90% [16]. Carbon capture ready for these plants can be as easy as reserving space for the compression unit and storage/transport units when new plants are built. The economically-viable distance to storage sites or end-users' needs to be calculated on a case by case basis. As mentioned previously, the existing hydrogen and chemical plants are relatively small in size compared to coal fired power plants and, in most cases, are located either in a chemical production area or coal reserve. Hence, it is easier to fit in and test carbon dioxide capture equipment in such plants rather than installing the larger size capture equipment to coal fired power plants for early trials of CCS. Having these plants retrofitted could be an easier option than retrofitting the large size power plants. Carbon dioxide could be either consumed locally or transported to other users still at a competitive price.

Figure 1 GE or Shell technology gasifiers and CTL plants in China (Data from [12])

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[e] *This is the only commercial scale direct CTL project in the world. Therefore it is included in this gasification paper.*

[17] indicate that China should produce most of its liquid fuel from coal for energy security reasons. Coal to liquid and coal to chemical plants have been proposed and built mostly in coal production areas. Capturing carbon dioxide from CTL plants is the next cheapest option when the gasification process is used. The special requirements for capture ready designs for CTL plants are due to the physical properties of the waste gas. According to [18], the average carbon dioxide to liquid fuel ratio is 0.57 tCO_2/barrel of oil and the ratio of carbon dioxide to coal consumed is about 1.2 in a process where coal is first gasified before the F-T reaction. According to [19], even with carbon capture and storage, the greenhouse gas emissions from a CTL plant are still 4% higher than ordinary gasoline. And the greenhouse gas emissions from CTL plants without CCS are 118.5% higher than ordinary gasoline. Therefore, CTL plants not only offer a cheaper option for carbon dioxide capture, but also have a social responsibility to make sure they can install a carbon capture unit. Figure 1 shows CTL or coal to chemical (CTC) plants that have installed, or will install, GE or Shell gasifiers. All of the approved CTL plants are in close proximity to the large coal reserves in Inner Mongolia.

Modern gasification technology normally means a much bigger coal input rate, higher oxygen consumption, higher temperatures and higher pressure than conventional small-scale gasifiers. It can also produce higher value chemical products at a much larger scale. The cost of carbon capture is slightly higher than hydrogen plant, but with a better carbon conversion rate inside the gasifier, and a bigger coal input. Differences between entrained-flow gasifier technologies can affect the overall efficiency of the gasifier, such as whether it is a dry feed or a slurry feed, whether it has a quench process before the gas comes out. But in all cases, with more coal going into the gasifier, more carbon dioxide can be captured with consequent economies of scale for transport and storage. These represent a growing industry in China that uses advanced gasifiers in coal production areas and at a much bigger scale than normal chemical plants.

The calculation by [18] showed a 28,400 tonnes carbon dioxide emitted, in order to produce 50,000 barrels of liquid fuel from coal. A barrel equals to 158.9 litre of oil with an average density of 0.8kg/L. That is to say, if all six of the current indirect CTL plants reach their highest production capacity, then roughly 102.7 million tonnes of carbon dioxide will be emitted into the atmosphere annually. See Appendix A for the list of planned CTL plants in China

Carbon capture and storage prospects are not only important for current plants, but also essential for the CTL plants in planning, since the long-term capacity is much greater than the current capacity. At the moment, only the Shenhua direct liquefaction in Inner Mongolia has announced that they will consider carbon capture ready for their plant. In the Fisher-Tropsch process at indirect liquefaction plants, a large amount of hydrogen is used for reaction. High concentration CO_2 normally emerges when H_2 is produced. That which is not needed in the next process could be captured using similar methods to those mentioned in the previous sections. Because of the large quantities of carbon dioxide at the plants, local consumption or small tests at nearby saline aquifers is not enough. Geological storage potential investigation is the key to making those plants capture ready. IGCC plants

Although pre-combustion capture from IGCC plants is considered one of the main options for carbon capture and storage, making IGCC plants capture ready is calculated to be not economically viable and technically difficult in most relevant studies [11, 13, 20]. There is the possibility of adding post-combustion capture units to the IGCC plants after the energy from the syngas is consumed, and after the gas turbine and steam turbine, before going into the atmosphere. In the Greengen Tianjing I project, a post-combustion test system will be added for testing the capture technology, and for the Greengen Tianjing II project, part of the syngas will be extracted for pre-combustion capture in a long term. See Appendix B for the list of planned IGCC plants in China.

2.4. Theoretical polygeneration concepts

[21] have analysed the performance and emissions on the co-production of electricity and hydrogen with carbon dioxide capture with an entrained-flow gasifier. In their model, the H_2/electricity rate was varied by changing the steam/carbon ratio or by letting the de-carbonised syngas bypass the pressure swing adsorption (PSA) unit. [22] propose a system for MeOH and electricity with carbon capture, which removes the shift process and replaces it with a chemical island to produce MeOH. The un-reacted syngas is separated, one stream goes back to produce MeOH and the other stream goes to a smaller scale shift reactor for carbon capture process with electricity generation. [23] further investigate the thermodynamic and economics of MeOH and electricity production. As a result of the system integration between the MeOH production and the electricity production, the system with syngas partly recycled to the methanol reactor can achieve 18.8% of primary cost saving compared to the plant which only produces MeOH and captures carbon dioxide in a conventional process. [24] also analyse the potential for using methanol as hydrogen carrier in the transition process to a hydrogen economy in China.

The above studies combine solid theoretical polygeneration concepts with modern entrained-flow gasifiers. The flexible product and economical investment will play a more important role when the polygeneration concept is more fully adopted, and the market will expand with the successful running of the large scale CTL plants. Carbon capture or capture ready design is considered in most of the polygeneration designs as it is a relatively new concept compared with other gasifier implementations. However, because of the ban on approving new CTL plants due to water consumption and high consumption on coal, the concept has only been developed in scientific papers so far [25].

3. Conclusion

China has most of the world's fixed-bed gasifiers. It is also constructing entrained-flow gasifiers at an extremely high rate, and the probability of China maintaining its fast construction rate in gasifiers is high. Although not many projects have included carbon capture and storage in the expansion or designs of the plan, carbon capture and storage has been taken into consideration by some of the gasifier operators in China. Capturing carbon dioxide from hydrogen plants or chemical plants where a high concentration of carbon dioxide is currently being emitted into the atmosphere constitutes an early opportunity for CCS in China. Carbon capture from fertilizer plants that have carbon dioxide in the flue gas in varying concentrations, should consider the capture option based on different processes. For CTL plants, carbon capture should be considered when the plants are being built since the amount of coal used in CTL plants is enormous compared with plants mentioned previously. The large amounts of carbon dioxide produced in CTL plants can result in cost effective capturing compared with capturing from different sources. The amount of carbon dioxide that can be captured from polygeneration plants varies when the product changes. However, polygeneration plants are one of the early pioneers to have taken carbon capture and storage into account in the planning stages in the gasification industry in China. If IGCC plants are proposed in China, carbon capture units should be installed from the plant's beginning to demonstrate the cost benefits of such technology.

Carbon capture from gasification processes should be taken more seriously in China in comparison with PC, for, when carbon capture becomes mandatory in the future, carbon dioxide produced from gasification streams will be relatively cheap. Hence, when planning a large-scale carbon mitigation roadmap, gasification plants should definitely be taken into consideration. In fact, they should play an essential role in the roadmap.

Although most of the gasification technologies can be considered as early demonstration opportunities, the potential for capturing carbon dioxide from gasification plants is not as great as capturing from pulverised plants in China due to the amount of carbon dioxide available and the time scale for large gasification development. Gasification project development is also far slower than pulverised coal plants. Hence, the focus for CCS should be pulverised coal plants in China, especially when considering the risk of carbon lock-in in large stationary emission points in China.

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Appendix A. Proposed CTL plants in China [13]

Company	Location	Current Capacity (liquid fuel) Mt/y	D/I	Operation time	Longterm capacity (Liquid fuel) Mt/y
Shenhua	Inner Mongolia	1	D	End of 2008	5
Yankuang	Shanxi	1	I	2010-2011	5
Luan	Shan'xi	0.16	I	Aug-08	0.48
Yitai	Inner Mongolia	0.16	I	Sep-08	0.48
Shenhua_Sasol	Shan'xi	3.2	I	2013-2014	6
Shenhua_Sasol	Ningxia	3.2	I	2013-2014	6

Appendix B. Proposed IGCC plants in China [13]

Company	Location	Capacity (MW)	Year	Notes
Yantai IGCC	Yantai (Shandong)	2* 300-400	Planned in 1999	The earliest planned IGCC plant, but has not yet been built (Shell Gasifier)
Greengen	Tianjing I (Lingang Industry zone)	250	2011 (2007)	Coal consumption: 2000t/d; TPRI 2 stage dry feed gasifier; 20% polygen; 80% electricity
Huaneng	Shantou (Guangdong)	100	Planned in 2007	Retrofit a heavy oil plant; Postcombustion capture 10% of the flue gas; TPRI gasifier
Datang	Dongguan (Guangdong, Mayong)	1600 (4*400)	2011	No plan for CO2 capture yet; 13b (CNY)
Greengen	Tianjing II	2*400	Planned in 2007	MOU with Tianjing Government